Modeling, Identification and Control of a Thermal glue based temporary fixing system : Application to the Micro-Robotic field.

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Modeling, Identification and Control of a Thermal Glue-Based Temporary Fixing System: Application to the Micro-Robotic Field

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***Abstract*— The purpose of this paper is to present a temporary fixing system based on a thermal glue that is well-adapted to micro-robotics. In the paper, this system is used to design a tool changer but can be generalized to other micro-robotic applications. A thermal modeling and an identification procedure are presented to propose a strategy to control the system. This system takes place into a micromanipulation station to gain flexibility, space and complexity. Indeed, to perform sequences of micromanipulation tasks (i.e. micro-assembly sequences), only one manipulator, able to use sequentially several end-effectors, has to be used instead of several dedicated to one specific task.**

I. Introduction

Micro-mechanic and micro-mechatronic devices are more and more used in industrial applications as in medical or research fields. These products have the particularity to include very small parts that must be assembled or manipulated for sorting or testing [1] [2] [3]. For example, in the field of material research, very small samples have to be manipulated often in confined space (test equipment) as a Scanning Electron Microscope (SEM) chamber [4]. Most hybrid Micro-Opto-Electro-Mechanical Systems (MOEMS) require the manipulation of small lenses or more generally optical micro-components [5] [6].

For large series production (computer, automotive industries...), special machines can be developed but their development costs are prohibitive for small series, as for medium or small size companies or for academic institutions. One solution consists in developing flexible micromanipulation systems to reduce the costs of micro-assembly [7]. In order to achieve such flexibility, we have designed manipulators able to use sequentially several dedicated end-effectors (i.e. parts in contact with the object to manipulate) with a new automatic exchange of these end-effectors. Each of them allows to manipulate one family of components that can be classified depending on their shape, size, material or consistency. In this aim, designing efficient temporary fixing systems could advantageously replace several dedicated micromanipulation systems by only one flexible. Such devices are already widespread in *macro-robotics*, but, in micro-robotics it is again more important to save space and to greatly increase the performances of the micromanipulation stations (diversity of objects to manipulate) without increasing significantly their complexity.

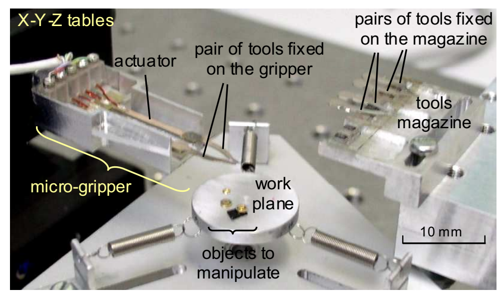

Fig. 1. Different parts of the micromanipulation station: a microgripper composed of a piezo-actuator and a pair of tools is fixed on micro-positioning tables. The objects to manipulate are placed on a work plane and several pairs of tools are available in a tools magazine.

For micro-robotics systems, different solutions for temporary fixing systems are reported in the literature. [8] [9] present different mechanical connexions adapted to micro-systems to fix together small pieces. [10] proposes a solution that permits to bring together several loops for a micro coil. These systems use the elastic deflection of beams (mechanical *clips*). Electrostatic or Van der Waals adhesive force generation can also be considered through recent works such as on the Gecko foot [11] [12]. Adhesive tapes (scotch®, post it®, gel pack®, Silicone polymers-PDMS) could also be used but the life-time of these systems is usually short and therefore the temporary fixing systems could hardly be re-used [13].

The present paper deals with a new way to generate a temporary fixing system based on a thermal glue that is well-adapted for micro-robotic applications. The resulting system has been tested on a micromanipulation station, composed of a micro-robot and a microgripper (Fig. 1), to exchange automatically the tips of the gripper (i.e. the end-effectors that will be called the tools in the present paper). The system of temporary fixing based on thermal glue is presented in Section

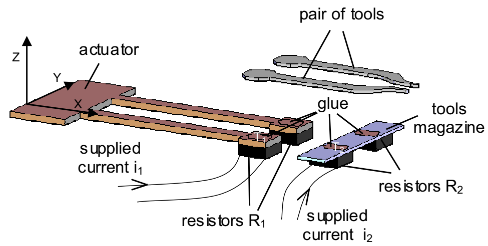

Fig. 2. Different parts of the tool changer: piezo-electric actuator, two tools made of Nickel, resistors and magazine made of glass.

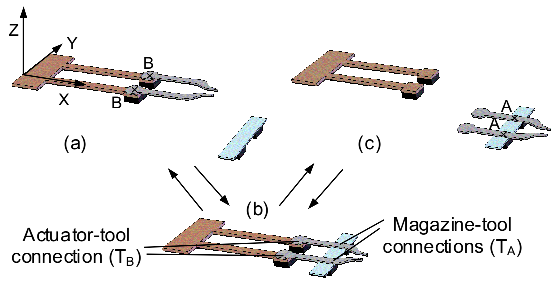

Fig. 3. Different configurations of the tool changer, (a) tools fixed on the actuator (micromanipulation configuration), (c) intermediate step and (c) tools fixed on the magazine (tool exchange configuration).

II showing the requirements and the constraints needed to ensure a good working in the case of the tool changer. The thermal modeling of the system will be presented in Section III followed by an identification procedure of the system's parameters in Section IV. Finally, experimental verifications will show the validity of the models and the working of the tool changer will be presented in the last Section.

II. Thermal glue based fixing system

Thermal glues support numerous cycles of heating/cooling (corresponding to liquefaction/solidification) without loosing their properties. In this paper, the crystalbond 555HMP (from Aremco Inc.) glue is used because it has the lowest melting point of the market. This glue is sold as a stick and is solid at ambiant temperature. The melting starts at 49 $^\circ$C and the glue is totally liquid at 62 $^\circ$C. For the cooling process, it is necessary to drop below 42 $^\circ$C to start the solidification process.

In order to develop a tool changer, i.e. a system able to exchange the tools of a microgripper (Fig. 1), a small quantity of glue, (approximately 4 nL per contact), is used at each interface between tool/actuator and tool/magazine. The different parts of this tool changer are presented in Fig. 2. 6 Ω Surface Mounted Device (SMD) resistors are placed under each contact. The supply of these resistors permits to control the temperature at the contact and therefore the glue state (then the state of the fixing). In this way, the tools can be alternatively fixed on the actuator or on the magazine. Both configurations and the intermediate step are reported in Fig. 3. The mechanical characterization of the system (forces transmitted by the connection between tools and actuator) are

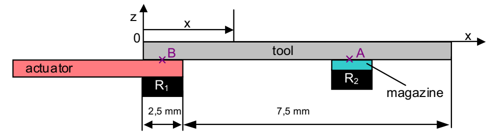

Fig. 4. Sketch of the system used in the modeling process.

detailed in [14]. The critical point of a tool exchange is the intermediate step (Fig. 3 (b)). Indeed, the control strategy must satisfy two requirements for a correct fixation of the tool on the magazine:

- the glue liquefaction at actuator/tool contact (location B) must be total, so the temperature must reach 62 $^\circ$C,
- the glue at tool/magazine contact (location A) must be solid to ensure the fixation of the tools on the magazine. so the temperature must stay below 49 $^\circ$C.

The role of A and B are reversed for a fixation of the tool to the actuator. Therefore, it is necessary to model the thermal behavior of the tool changer during this intermediate step to achieve such a working principle.

III. Thermal Modeling

The key point to ensure the good working of the tool changer is to be sure that it is possible to detach the fixing area at the point B (Fig. 4) without releasing the fixing area at the point A when resistors of point B are supplied. The modeling of thermal behaviour also permits to determine the parameters to control the resistors supplying (intensity and duration) during a tool exchange. The system is described on Fig. 4. Thermal behaviour is then deducted from the energy conservation law [15]:

$$\int_V \rho \cdot C \cdot \frac{\partial T}{\partial t}\, dV = -\int_S \vec{q} \cdot \overrightarrow{n_{ext}}\, dS + \int_V Q\, dV \qquad (1)$$

with the parameters reported in the TABLE I. In this work, the

Symbol	parameter	unit
ρ	mass density	kg/m^3
C	calorific capacity	J/Kkg
V	volume of the considered element	m^3
S	external surface of the considered element	m^2
$\vec{q}$	heat flux density	W/m^2
Q	volumic heating source	W/m^3
$\overrightarrow{n_{ext}}$	unit vector, normal to the considered surface, oriented to the exterior of the considered element	
λ	conduction coefficient	W/mK
h	convection coefficient	W/m^2K

TABLE I

Parameters used in the equations (1) and (2)

thermal radiation is neglected and the heating flux density is composed of the conduction and the natural convection ($\vec{q} = \overrightarrow{q_{cond}} + \overrightarrow{q_{conv}}$). According to the Fourier's law, $\overrightarrow{q_{cond}} = -\lambda \cdot \overrightarrow{\nabla T}$ where λ is the conduction coefficient of the considered element (resistor or tool). According to the conducto-convective

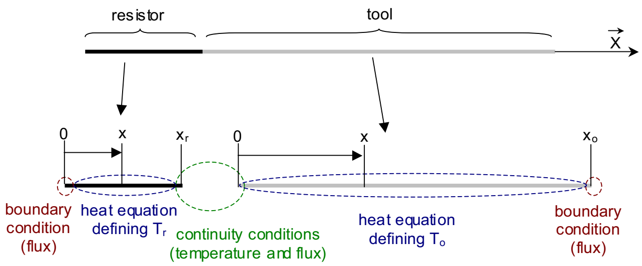

Fig. 5. Modeling split and hypothesis.

approximation law $\overrightarrow{q_{conv}} = h \cdot (T - T_\infty) \cdot \overrightarrow{n_{ext}}$, where h is the convection coefficient at the surface of the element and T_∞ is the ambiant temperature. Due to the thickness of the tools (0.18 mm), the temperature will be considered constant in the cross-section. The modeling is then reduced to a one dimensional problem along the x axis. According to these hypotheses, equation (1) can be written as the *local form*:

$$\rho \cdot C \cdot \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left[\lambda \cdot \frac{\partial T}{\partial x}\right] - \widetilde{h} \cdot (T - T_\infty) + Q \tag{2}$$

with T a fonction of space and time $T(x,t)$ and $\widetilde{h} = 2 \cdot \frac{(w+e) \cdot h}{w \cdot e}$. w and e are respectively the width and the thickness of the element. The volumic – local – heating source Q is distributed along the x position. In the resistor, this local source is:

$$Q = \frac{P_{elec}}{V_{SMD}} = \frac{R \cdot i^2}{V_{SMD}} \tag{3}$$

P_{elec} is the electrical power, i the electric current feeding the resistor R and V_{SMD} represents the total volume of this resistor. To determine the strategy to control the resistors, a simplified model is used neglecting the influence of the actuator and magazine (FIG. 5). The validity of these hypothesis will be experimentally verified in Section V. Then, an analytical model of the steady state response is used (Section III-A) to identify the thermal parameters of the resistor and the tools (Section IV). Using these parameters, a numerical model of the transient behavior has been developed (Section III-B) leading to the control strategy.

A. Analytical solutions

By splitting the system into two parts (a resistor and a tool as shown in FIG. 5), it is possible to solve analytically the steady-state response of equation (2). The expressions inside the resistor (subscript r) and inside the tools (subscript o) are:

$$\begin{cases} T_r(x) = \alpha_r \cdot e^{\sqrt{\frac{\widetilde{h_r}}{\lambda_r}} \cdot x} + \beta_r \cdot e^{-\sqrt{\frac{\widetilde{h_r}}{\lambda_r}} \cdot x} + T_\infty + \frac{Q}{\widetilde{h_r}} \\ T_o(x) = \alpha_o \cdot e^{\sqrt{\frac{\widetilde{h_o}}{\lambda_o}} \cdot x} + \beta_o \cdot e^{-\sqrt{\frac{\widetilde{h_o}}{\lambda_o}} \cdot x} + T_\infty \end{cases} \tag{4}$$

α_r, β_r (resp. α_o and β_o) are the coefficients for the resistor (resp. the tool). They depend on these boundary conditions:

- no flux at the extremity of the considered element,
- temperature and flux continuity between the resistor and the tool.

Then, these four coefficients can be expressed as:

$$\begin{cases} \alpha_o = \dfrac{Q \cdot \sqrt{\frac{\lambda_r}{\widetilde{h_r}}} \cdot (1 - e^{2 \cdot \sqrt{\frac{\widetilde{h_r}}{\lambda_r}} \cdot x_r})}{d} \\ \text{with } d = \lambda_r \cdot \sqrt{\frac{\widetilde{h_r}}{\lambda_r}} \cdot (1 + e^{2 \cdot \sqrt{\frac{\widetilde{h_o}}{\lambda_o}} \cdot x_o}) \cdot (e^{2 \cdot \sqrt{\frac{\widetilde{h_r}}{\lambda_r}} \cdot x_r} - 1) \\ \qquad + \lambda_o \cdot \sqrt{\frac{\widetilde{h_o}}{\lambda_o}} \cdot (e^{2 \cdot \sqrt{\frac{\widetilde{h_o}}{\lambda_o}} \cdot x_o} - 1) \cdot (e^{2 \cdot \sqrt{\frac{\widetilde{h_r}}{\lambda_r}} \cdot x_r} + 1) \\ \beta_o = \alpha_o \cdot e^{2 \cdot \sqrt{\frac{\widetilde{h_o}}{\lambda_o}} \cdot x_o} \\ \alpha_r = \beta_o \cdot \dfrac{(e^{-2 \cdot \sqrt{\frac{\widetilde{h_o}}{\lambda_o}} \cdot x_o} + 1)}{(e^{\sqrt{\frac{\widetilde{h_r}}{\lambda_r}} \cdot x_r} + e^{-\sqrt{\frac{\widetilde{h_r}}{\lambda_r}} \cdot x_r})} - \dfrac{Q}{\widetilde{h_r} \cdot (e^{\sqrt{\frac{\widetilde{h_r}}{\lambda_r}} \cdot x_r} + e^{-\sqrt{\frac{\widetilde{h_r}}{\lambda_r}} \cdot x_r})} \\ \beta_r = \alpha_r \end{cases} \tag{5}$$

For the dynamic behaviour, only Green methods can be used to solve analytically the equation (2). They are complex and require the knowledge of a Green function [16], that is why for our application, we decided to use a numerical resolution.

B. Numerical solutions

A Finite Difference Method (FDM) was chosen. It permits to replace the Ordinary Differential Equation (2) (ODE) with a recurrent equation using both space and time sampling. First order derivative was replaced with Euler approximation and second order derivative was replaced with the central difference approximation [17]. The temperature along the tool which depends on space and time $T(x,t)$ is therefore approximated by the serie $T(i,j)$ with i the index of space and j the index of time sampling. After some handling, this recurrent equation can be written as:

$$\begin{aligned} T(i,j+1) = & \frac{\lambda(i+1)}{(\Delta x)^2} \cdot \frac{\Delta t}{\rho(i) \cdot C(i)} \cdot T(i+1,j) \\ & + (1 - \frac{\lambda(i+1) + \lambda(i)}{(\Delta x)^2} \cdot \frac{\Delta t}{\rho(i) \cdot C(i)} \\ & - \widetilde{h(i)} \cdot \frac{\Delta t}{\rho(i) \cdot C(i)}) \cdot T(i,j) \\ & + \frac{\lambda(i)}{(\Delta x)^2} \cdot \frac{\Delta t}{\rho(i) \cdot C(i)} \cdot T(i-1,j) \\ & + \widetilde{h(i)} \cdot \frac{\Delta t}{\rho(i) \cdot C(i)} \cdot T_\infty + \frac{\Delta t}{\rho(i) \cdot C(i)} \cdot Q(i) \end{aligned} \tag{6}$$

This equation for all the space sampling can also be conveniently transformed into a state space model where each state corresponds to the temperature at one position of the element (space sampling) $\mathbf{X}(j) = \{T(1,j) \cdots T(N,j)\}^T$ and the command $\mathbf{U}(j)$ is composed of the thermal source at each position and of the ambiant temperature $\mathbf{U}(j) = \{Q(1,j) \cdots Q(N,j)\ T_\infty\}^T$:

$$\begin{cases} \mathbf{X}(j+1) = \mathbf{A} \cdot \mathbf{X}(j) + \mathbf{B} \cdot \mathbf{U}(j) \\ \mathbf{Y}(j) = \mathbf{C} \cdot \mathbf{X}(j) + \mathbf{D} \cdot \mathbf{U}(j) \end{cases} \tag{7}$$

The **A** matrix is constructed from the recurrent equation (6) and from the boundary conditions. The detailed content of the **A** matrix is not reported in this paper because of its complexity and size. The **C** matrix depends on the temperature locations considered as output. The **D** matrix is null in our case.

These two models (analytic for the steady-state response i.e. equation (4) and numeric for the transient response i.e. equation (6)) will be used to compute the temperature into the tools according to the current in the resistor.

IV. Parameters identification procedure

As pointed out in the previous Section, the steady-state and transient behaviour of the heating/cooling process for the tool changer can be predicted by using two different models: an analytical model for the steady-state response and a finite difference model for the transient response. To solve these models, in the particular case of the tool changer, it is of course necessary to know the numerical value of the parameters λ, $\tilde{h}$ and $\rho \cdot C$ as well for the resistor as for the tool. Nevertheless, these parameters are not known because they depend on the geometry, the materials and the fabrication process (tools are made using a UV-LIGA process). To determine the numerical values of the parameters used in these models, an identification procedure based on the analytical model is proposed. An identification procedure using the numerical model is also reported to demonstrate that this kind of method is not well adapted to micro-robotics.

A. Identification procedure based on the steady-state analytical solutions

To identify the conduction and convection parameters, the steady-state analytical solution described by equation (4) can be used. As four parameters have to be identified, four steady state measurements are necessary. But, due to the complexity of the obtained equations, the system cannot be solved. For this reason, we have developed a method that consists in eliminating the h and λ coefficients to identify the following parameters :

$$\alpha = \sqrt{\frac{\widetilde{h_r}}{\lambda_r}} \qquad \beta = \sqrt{\frac{\widetilde{h_o}}{\lambda_o}} \qquad \gamma = \frac{1}{\widetilde{h_r}} \tag{8}$$

The resistor at the actuator-tool contact has been supplied and a thermocouple (with 25 μm in diameter) mounted on a manipulator has been used to measure the steady state temperature along the tool and the resistance. Four measurements, at four different points in the resistance and three in the tool have been used to determine two equations, one depending only of α the other only of β. After a numerical resolution, these parameters were obtained and re-used to know γ giving the following values:

$$\left\{\begin{array}{l} \alpha = \sqrt{\frac{\widetilde{h_r}}{\lambda_r}} = 49 \\ \beta = \sqrt{\frac{\widetilde{h_o}}{\lambda_o}} = 96 \\ \gamma = \frac{1}{\widetilde{h_r}} = 1.85 \cdot 10^{-4} \end{array}\right. \Rightarrow \left\{\begin{array}{l} \frac{h_r}{\lambda_r} = \frac{w_r \cdot e_r}{2 \cdot (w_r + e_r)} \cdot \alpha^2 = 0.39 \\ \frac{h_o}{\lambda_o} = \frac{w_o \cdot e_o}{2 \cdot (w_o + e_o)} \cdot \beta^2 = 0.77 \\ h_r = \frac{w_r \cdot e_r}{2 \cdot \gamma \cdot (w_r + e_r)} = 35.3 \end{array}\right. \tag{9}$$

For the last equation, the model defined by equations (4) has been re-written using h_o as parameter (h_r, λ_r and $\frac{h_o}{\lambda_o}$ are known). The comparison of the plotted solution with measurements allowed to deduce the physical coefficients as follows:

$$\left\{\begin{array}{l} h_r = 35.3 \quad W/m^2K \\ \lambda_r = 90 \quad W/mK \end{array}\right. \qquad \left\{\begin{array}{l} h_o = 38 \quad W/m^2K \\ \lambda_o = 49.3 \quad W/mK \end{array}\right. \tag{10}$$

Finally, these parameters were used in the transient numerical model. Coefficients ρ and C (see Section III-B) influes only on the transient behavior of the system. Standard values of ρ were used but values for C were obtained by comparison between the results given by the numerical model (for several values of C) with measurements giving the following values:

$$\left\{\begin{array}{l} \rho_r = 2520 \ kg/m^3 \\ \rho_o = 8900 \ kg/m^3 \end{array}\right. \left\{\begin{array}{l} C_r = 790 \ J/K \cdot kg \\ C_o = 765 \ J/K \cdot kg \end{array}\right.$$

B. Identification procedure based on the transient numerical solutions

The Finite Difference Method based on the equation (6) corresponds to a recurrent equation according to the space variable (subscript i) or according to the time variable (subscript j). Therefore, an ARX identification principle can be applied considering either the space or the time as sampling step. These two procedures were conducted but only one – according to the space sampling along x – will be presented in this paper. The ARX method is an identification procedure applies to a model of the form [18]:

$$\begin{aligned} y(k+1) = &- a_1 \cdot y(k) - \cdots - a_n \cdot y(k-n+1) \\ &+ b_1 \cdot u(k) + \cdots + b_m \cdot u(k-m+1) \end{aligned} \tag{11}$$

A following matrix convention will be used here:

$$\tilde{\mathbf{y}}(k \mid \theta) = \varphi(k)^T \cdot \theta \tag{12}$$

$\tilde{\mathbf{y}}(k \mid \theta)$ is the calculation of $y(k+1)$ from past data $\varphi(k)$ (output and input measurements available at discrete time k) and from estimated parameters θ:

$$\left\{\begin{array}{l} \varphi(k) = \left(-y(k) \ \ldots \ -y(k-n+1) \ u(k) \ \ldots \ u(k-m+1)\right)^T \\ \theta = \left(a_1 \ \ldots \ a_n \ b_1 \ \ldots \ b_m\right)^T \end{array}\right. \tag{13}$$

Keeping the time constant and using the space sampling (for example, the steady-state response at $j = \infty$ can be used), equation (6) can be rewritten with $\widetilde{T} = T - T_\infty$ inside the resistor and the tool as:

$$\left\{\begin{array}{l} \widetilde{T_r}(i+1,j) = a_r \cdot \widetilde{T_r}(i,j) - \widetilde{T_r}(i-1,j) - b_r \cdot Q \\ \widetilde{T_o}(i+1,j) = a_o \cdot \widetilde{T_o}(i,j) - \widetilde{T_o}(i-1,j) \end{array}\right. \tag{14}$$

with $a_r = -(2 + \frac{\widetilde{h_r} \cdot \Delta x^2}{\lambda_r})$, $b_r = -\frac{\Delta x^2}{\lambda_r}$ and $a_o = -(2 + \frac{\widetilde{h_o} \cdot \Delta x^2}{\lambda_o}$.

If one define $\theta_r = \left(a_r \ b_r \ 1\right)^T$, $\theta_o = \left(a_o \ 1\right)^T$, $\tilde{\mathbf{y}}_r = \left(y_r(3) \ y_r(4) \ \ldots \ y_r(n_r)\right)^T$, $\tilde{\mathbf{y}}_o = \left(y_o(3) \ y_o(4) \ \ldots \ y_o(n_o)\right)^T$

and the following notations:

$$\varphi_r^T = \begin{pmatrix} -y_r(2) & Q & -y_r(1) \\ -y_r(3) & Q & -y_r(2) \\ \vdots & \vdots & \vdots \\ -y_r(n_r-1) & Q & -y_r(n_r-2) \end{pmatrix}$$
$$\varphi_o^T = \begin{pmatrix} -y_o(2) & -y_o(1) \\ -y_o(3) & -y_o(2) \\ \vdots & \vdots \\ -y_o(n_o-1) & -y_o(n_o-2) \end{pmatrix} \quad (15)$$

Two identifications problems have to be solved:

$$\tilde{\mathbf{y}}_r = \varphi_r^T \cdot \theta_r \quad and \quad \tilde{\mathbf{y}}_o = \varphi_o^T \cdot \theta_o \quad (16)$$

The estimate $\tilde{\theta}$ of θ can be found using the Least Square Method [19]: $\tilde{\theta}_r = (\varphi_i \cdot \varphi_i^T)^{-1} \cdot \varphi_i \cdot \mathbf{y}_i$ with $i \in r, o$.

The parameters a_r, b_r and a_o were identified with a great accuracy (10^{-3} for a_r and a_o, 10^{-9} for b_r). Nevertheless, a_r and a_o are extremely close to the value of -2 and b_r worth nearly nought generating an inaccurate determination of the *physical parameters* (λ_r, $\widetilde{h_r}$ and $\frac{\widetilde{h_o}}{\lambda_o}$). For b_r, this inaccuracy strongly depends on the value of Δx meaning that the accuracy of the method would be improved if applied to bigger systems (over than 1 mm in size). The a_r and a_o parameters do not depend on the size of the objects but on the physical problem, so, whatever the size of the studied device, it is always difficult to use these parameters to determine $\frac{\widetilde{h_r}}{\lambda_r}$ and $\frac{\widetilde{h_o}}{\lambda_o}$.

V. Comparison between models and experimental measurements

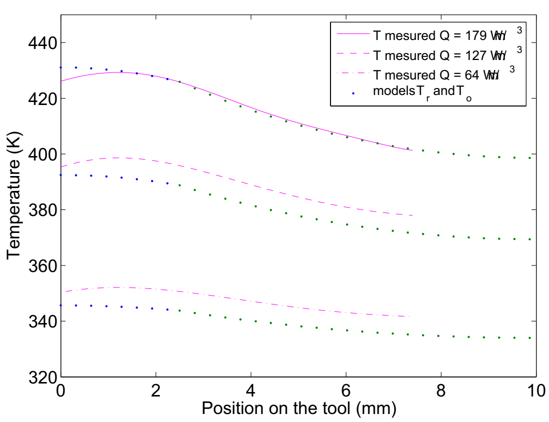

Fig. 6. Comparison between the steady-state model and experimental measurement for three different constant heat sources.

The steady-state behaviour resulting from the identification procedure and the equation (4) was compared to the experimental steady-state response for three different sources (Fig. 6). The temperature is measured with the same micro thermocouple attached to the manipulator. The identification procedure was based on the experimental measurements with $Q = 179$ W/m^3 therefore the fitting between model and measurements are the best for this value.

For the two other sources, the model is accurate for the prediction of the difference of temperature between two locations but less accurate for the absolute temperature at one location. For our application, this solve the most important problem which is to evaluate the temperature difference between point A and point B (see Fig. 4) to propose a control for the resistors.

As previously mentioned, the modeling is based on a simplified description of the system as it does not take into account the influence of the actuator and the magazine (see Fig. 5). Nevertheless, the identification procedure and the fitting between the models and the experiments show that these simplifications are acceptable. Fig. 7 reports the comparison between the results of the numerical model (6) and experimental transient responses of the system using the parameters previously identified. The temperatures resulting from the modeling are close to the experimental temperature then the dynamic model can be used with confidence. The modeling is then valid to design the control for the tool changer.

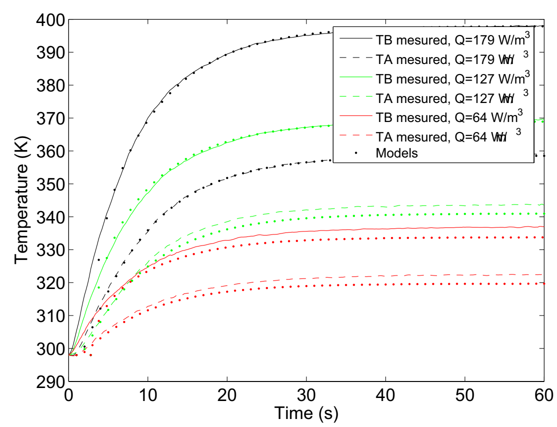

Fig. 7. Comparison between the transient model and experimental measurement for three different sources and a step input.

VI. Working of the tool changer

In the previous Sections, we showed that the control strategy must satisfy two requirements: the glue of the heated contact must be totally liquefied and the glue at the other contact must be solid. The previous modeling allows to select easily the required currents in R_1 and R_2 as shown by Fig. 8. This compromise simultaneously guarantees the liquefaction of the glue at the desired contact, the solid state of the glue at the other contact and a good working of all the elements.

Using the micromanipulation station presented in Fig. 1, sequences of tool exchanges (Fig. 9) can be performed based on this control strategy. At the beginning (picture 1), a 300 μm cubic part is manipulated using well-adapted tools. In the second picture, the tools are set down to the magazine (cooling of the tool/magazine contact then heating of the tool/actuator

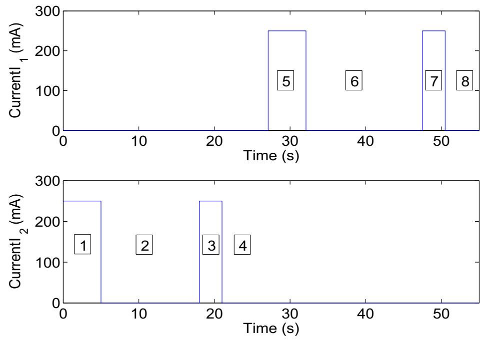

Fig. 8. Cycles of powering resistors of the actuator (R_1) and of the magazine (R_2): (1) heating of R_2 (2) manipulation configuration (tools fixed on actuator) (3) heating of R_2 (4) fixing this pair of tools in the magazine (5) heating of R_1 (6) tool exchange configuration (tools fixed on magazine) (7) heating of R_1 (8) fixing the pair of tools at the actuator and magazine.

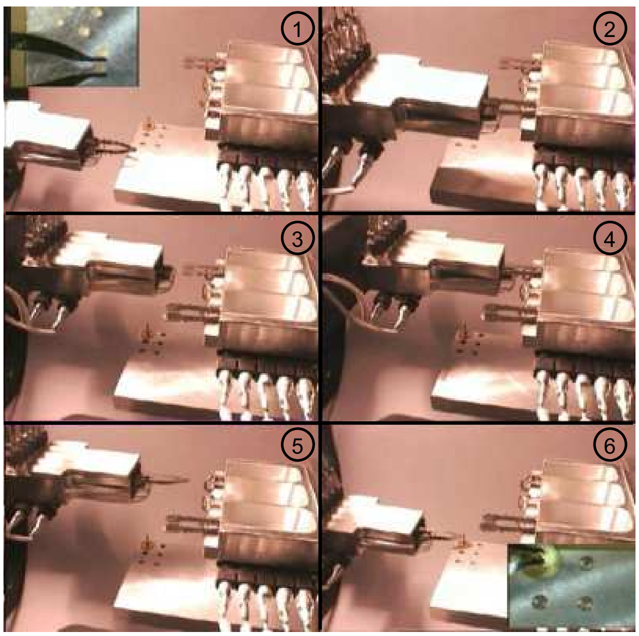

Fig. 9. Sequence for a tool exchange using the temporary fixing system.

contact). Then, the actuator can move alone to take the second pair of tools (picture 3). In the picture 4, the second pair of tools is fixed on the actuator (cooling of the tool/actuator contact then heating of the tool/magazine contact). Finally, we can move the new tools/actuator set as shown in picture 5 and manipulate an other kind of parts (here a circled section gear wheel) with this second pairs of tools (picture 6). Sequences of tool exchanges are performed automatically requiring less than three minutes each.

VII. Conclusion

This paper presents a new temporary fixing system adapted to the micromanipulation or micro-assembly tasks. This system is based on a thermal glue. The paper first explains the requirements for a good working of the system. This leads to the development of two thermal models for the system. An identification procedure has been applied to fit the model results with the experimental measurements. The results obtained permit to propose an efficient control of the temperature and then of the glue state used for the fixing system. This device is used for a tool changer to increase the flexibility of a micro manipulation station. This automatic system also permits to save space and increases greatly the possibilities of the station (size, shape of the samples to manipulate) without increasing significantly its complexity. This temporary fixing system is well-adapted to this tool changer and especially to micro-robotic applications, but, it can also be generalized to any other microsystems. This tool changer has been successfully tested in a SEM and future works will concern the comparison of the thermal behavior of this device in air and vacuum environments.

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